CEMENT AND LIME MANUFACTURE

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Lime Kilns in Germany.

MANY details of the methods used for burning lime in the British zone in Germany are given by Mr. C. B. Taylor and Mr. B. J. Gee in a report entitled "The German Limeburning Industry" (H.M. Stationery Office. 1946. Price 14s.) prepared by the British Intelligence Objectives Sub-Committee.

In Westphalia the limestone belongs to the Devonian period, and in Wurtemburg to the Jurassic period. The majority of Devonian limestones contained significant percentages of either silica or magnesia or both, and in several quarries dolomitic limestone is found adjacent to lime with a high calcium content or feebly hydraulic material. The Jurassic limestone has a $CaCO_3$ content up to 99.5 per cent., and is snow white, remarkably free from contamination, and of consistent porcellaneous texture. The largest works at Dornap and Widfrath, however, use limestone that is seriously contaminated with clay and other impurities. All raw materials are therefore washed after crushing and screening.

The methods of quarrying do not differ appreciably from those in use in Britain, but well-hole drilling is not employed. Aerial ropeways are extensively used. Several types of kilns are installed but many are shut down owing to the scarcity of coal and labour.

Hoffmann Kilns.

The Hoffmann kiln is commonly used although apparently no new kilns of this type are being installed. They are extensively used for producing lime of high quality and are worked with a relatively low consumption of fuel. The daily output of some of the Hoffmann kilns, all of which burn slack coal, varies from 30 to 40 tons, with a fuel consumption of about 20 per cent., although the reputed output of each kiln in a battery of six near Menden exceeded 100 tons daily. Two kilns at Hohenlimberg each produced 50 to 55 tons per day with a fuel consumption of 17 per cent.; two at Wulfrath, 80 tons each per day with 22 per cent. fuel consumption; and one at Heggan, 60 tons per day with 19 per cent. fuel consump-

tion. Two of the eight Hoffman kilns at the large Dornap works are in service and charged with stone graded from 8 in. to 16 in. It is claimed that the Hoffmann kilns burned slack coal at the rate of 475 tons per month, the monthly output of lime being about 9,000 tons.

It is said that the popularity of Hoffmann kilns in Germany is due to the fact that the lime produced is of better quality for many purposes than that obtained from shaft kilns.

Straight-Shaft Kilns.

Many works employ the conventional vertical straight-shaft kiln, usually burning coke. Particulars of some of these kilns are given in the following.

An installation near Halle, Westphalia, consists of two small cylindrical vertical shaft mixed-feed kilns each about 30 ft. in height and of masonry construction. The raw material is hydraulic limestone graded from 8 in. to 3 in. Three men only are employed in each shift at these works which are in part production and have a daily output of 8 to 9 tons of lime. The latter contains 85 to 90 per cent. of calcium oxide. The coke consumption was 20 per cent.

Another works in the same locality has three shaft-kilns, one of which is in operation. The limestone is hard hydraulic material containing 89 per cent. of calcium carbonate. The capacity of these three kilns is 70 tons daily with a consumption of small coke of 20 per cent.

At a nearby works six old cylindrical masonry kilns are installed. When all are in operation the daily output is said to be 75 to 80 tons with a coal consumption of 25 per cent., but the present output employing 16 men is less than one-third of this quantity. The lime contains about 80 per cent. of calcium oxide.

An unusual kiln near Brilon, Westphalia, is a cylindrical structure constructed of mild steel plates and is about 53 ft. high and has an external diameter of 8 ft. 6 in. to 9 ft. 6 in. The steel shell is surrounded and supported by a reinforced concrete tower. The raw material is taken to the top of the kiln in jubilee-type wagons up an inclined ramp. Stone and coal are tipped into the kiln without special precautions. The method of discharging the kiln is to rake the lump lime off the two sloping grates. Although it is not working at present, the output of this kiln is said to be 600 tons per month and the monthly coke consumption 150 tons.

An installation of six shaft kilns, near Menden, three of which are in operation, is interesting as the kilns are constructed of reinforced concrete with walls $7\frac{3}{4}$ in. thick, and are contained within a large concrete building. The heights of the kilns are from 59 ft. to 65 ft. 6 in. The external diameter is 19 ft. 8 in. and the internal working diameter is 13 ft. $1\frac{1}{2}$ in. with a slight taper downwards. The kilns are fired with coke, and the fuel and stone are deposited in separate layers. Four of the kilns are provided with manual drawing arrangements which are preferred, owing to less maintenance, to the mechanical drawing used for the other two kilns. Each kiln has a daily output of 80 tons of lime. The coke consumed in the six vertical kilns was 80 tons per day. Another shaft kiln at Geislingen, about 55 ft. high and about 5 ft. in diameter, has walls of reinforced

concrete. The lining is of ordinary firebrick with an insulated backing of expanded-clay blocks.

Two mixed-feed shaft kilns are in operation near Iserlohn and have a nominal output of 40 to 50 tons per day with a coke consumption of 20 per cent. A feature of these kilns is that they are lined with dolomite blocks produced in a press using the sintered product of cupolas installed at the same works. The life of these linings is said to be about one year.

Sintered dolomite, made in rotary kilns, is also a principal product of a large works at Halden, which also produces, in shaft kilns, dolomitic lime and high-calcium lime. This works has two rotary kilns 100 m. long with an internal diameter of 2.50 m., one rotary kiln 70 m. long, and another 20 m. long. Only the last-mentioned is working. There are four shaft kilns, each about 90 ft. high and 15 ft. diameter externally. The hearths of these kilns consist of a small table, with scraper arms, rotating three times per hour. Each kiln produces 5 tons of sintered dolomite per hour with a consumption of furnace coke of 30 per cent.

There are eight mixed-feed shaft kilns at Wulfrath, some of which are working, and each has a daily output of 80 tons when burning stone graded from 3 in. to 4¾ in. The consumption of coke is 20 per cent. The kilns are of masonry construction with manual charging and drawing.

For lime burning at a works near Aachen there are three small mixed-feed shaft kilns the fuel for which is a mixture of one part of furnace coke to two parts of washed anthracite duff. The output is 80 tons per day with a fuel consumption of 27 per cent. It is claimed that forced draught would increase the output to over 100 tons per day and reduce the fuel consumption to 25 per cent.

Four mixed-feed vertical shaft kilns are situated near Ulm. The shells of two are of brick, and of the other two mild steel plate. The height is 15 m.; the diameter of the larger kilns is 1.6 m and of the smaller 1.4 m. With a coke consumption of 18 per cent. the daily output of the larger kiln is 20 tons, and of the smaller 15 tons, when working a seven-day week of 24 hours a day.

Gas-Fired Kilns.

Except at steelworks there are few gas-fired kilns. At the Herman Goring steelworks at Wunadorf the four kilns are of British design and were put into operation in the years 1941 to 1943. They consist of cylindrical steel shells erected on reinforced concrete bases, and have an overall height of 112 ft. excluding the base. The maximum internal diameter is 17 ft. 6 in. reducing to 15 ft. 5 in. at the top. The kilns are lined in the top sections with common brick for the back lining and ordinary firebrick for the front lining. In the firing zone the front lining is a special alumina brick. Insulation bricks are used in the firing zone adjacent to the shell. Special large burner blocks are employed for the water-cooled burners. The drawing of the kiln is effected through pneumatically-operated clam-shell doors. A batch of 5 tons of lime is drawn from each kiln every 40 to 60 minutes. The nominal output is 145 tons per day. The gas consumption is 6,000 cu. m. per hour. Blastfurnace gas, having the following analysis and a calorific value of over 108 B. Th. U. per cubic foot, is used.

	Blastfurnace Gas.	Kiln exhaust gas.
	%	%
Carbon dioxide	7.8	26.55
Oxygen	0.2	2.91
Carbon monoxide ..	29.8	0.50
Hydrogen	2.2	—
Methane	0.2	—
Nitrogen	59.8	—

The thermal efficiency was about 55 per cent. On the three kilns thirty men were employed working in three shifts.

Four gas-fired kilns of masonry construction and approximately 19 m. high are installed at a works at Heggen. They are of oval cross-section. Each kiln has ten gas inlets at one level. The kilns are drawn by hand, the output being 45 tons in 24 hours. The lining in the burning zone is of high-silica bricks and has a life of eight to twelve months. Producer gas having a calorific value of 168 B. Th. U. per cubic foot is used and the consumption of lignite in producing the gas is about 30 per cent. of the lime produced in the kiln.

Seegar Kilns.

A few works have vertical mixed-feed kilns of the type designed by Dr. Seegar. The standard kiln of this type is a vertical cylindrical steel shell lined with refractory material and mounted on a base of either steel or reinforced concrete. The kiln is provided with a skip hoist for elevating the stone and coke and has a patented charging device. The kiln is hand-drawn but is designed for easy operation. It is provided with forced draught supplied to a central mushroom tuyere and two chimneys are mounted on the top of the kiln but below the charging device.

The cylindrical section of the kiln is 61 ft. 8 in. high with an outside diameter of 15 ft. 1½ in.; the inside diameter is 11 ft. 9¾ in. The refractory lining has a thickness of 19¾ in. The section of the kiln below the drawing level varies in height but an average dimension of 26 ft. 3 in. is usual. Thus the overall height is about 88 ft. 9 in. The nominal output is 90 to 100 tons of lime per day when operated continuously for 24 hours a day and for 6½ or 7 days a week. The coke used is of the hard furnace type and the fuel consumption is claimed to be 20 per cent. of the lime produced.

The charging arrangements are designed essentially for the control of the segregation of the stone and the even distribution of the coke. The cylindrical section of the shell is provided at the top with a truncated section, giving a final diameter of approximately 6 ft. A receiving hopper is mounted above the kiln, the tapered bottom section of the hopper projecting into the kiln, the hopper being supported on rollers. The roller path is attached to the kiln shell and the receiving hopper rotates concentrically with the kiln by means of a bevel-gear drive. The stone is discharged from the skip-hoist at a point on one side of the

vertical centre line of the kiln into a chute which delivers the charge into the receiving hopper. This method of delivery unavoidably causes the segregation of the stone, but to compensate for this segregation in the receiving hopper the bevel-gear drive rotates the hopper through one-quarter, one-half, or three-quarters of a turn at each successive charge. Thus the smaller pieces of stone are distributed around the circumference of the kiln. The actual discharge from the rotating hopper is by a bell which is operated by a mechanically controlled electric winch. Mounted on the same vertical shaft as and below the bell is a hollow truncated cone, below which is a spider or spreader.

When the kiln is being charged the vertical shaft and its attachments are lowered and the material gravitates over the sloping sides of the bell, most of it falling on to a basket of static bars projecting inwards around the periphery of the kiln. The smaller sizes pass through this grid, while the larger stone is deflected back to the centre of the kiln. The grid thus counteracts undesirable segregation and the result is that the largest stones with some smalls are in the middle of the kiln while the smaller stones are at the sides.

When coke is being charged, the vertical shaft is raised until the lower cone is virtually in contact with the bottom edge of the receiving hopper. The coke thus passes through the cone, cascades over the spreader, is delivered in an even circular bed on top of the stone, and is nowhere in contact with the lining. The usual procedure is to charge four or five skips of stone followed by one of coke.

The drawing arrangement is on the " Anker " principle. The bottom of the kiln is provided with a sloping hearth in the shape of a very shallow rectangular pyramid from which rises the mushroom-type tuyere. The hearth is arranged with the four slopes delivering the lime to four drawing holes provided with hinged cast-iron doors disposed symmetrically around the bottom of the kiln. The hearth level is about 3 ft. above the floor level on which the four lime drawers work. The operators rake about 12 to 15 tons of lime from the four draw holes into a receiving hopper arranged vertically below the kiln. The lime falls by gravity from the lip of the hearth through an aperture between the shell of the kiln and the barrier wall of the hopper. The kilns are drawn every 2½ to 3 hours.

The lime-receiving hopper is arranged vertically below the kiln, and acts as a measuring device as well as a storage bunker. The arrangement for discharge from the bunker is not standardised, and includes reciprocating torpedo conveyors, rubber-band conveyors, shaker screens, and simple clam-shell doors.

The kilns are lined with refractory materials, alumina bricks being used for the facing in the burning zone and ordinary siliceous blocks elsewhere with an insulation backing adjacent to the shell.

The Seegar kiln at a works at Messinghausen, Westphalia, has an output of 75 to 85 tons of lime in 24 hours and a coke consumption of 18 per cent. The size of the stone fed into the kiln is 2 in. to 7¾ in. The coke is in pieces from 1¼ in. to 1½ in. in size.

Two Seegar kilns are installed at Hohenlimberg, one having been erected in 1938 and the other in 1941. The linings are common firebrick and have a life

of from one to two years. The kilns are manually drawn. The fuel consumption is about 20 per cent.

Of the sixteen kilns at the Dornap works eight are Seegar kilns, four being erected in 1939 and the remainder in 1941. The stone is graded from about 2½ in. to 8 in. Each kiln has a nominal output of 90 tons per day and a coke consumption of 18 per cent. The kilns are manually drawn.

At a large works at Wulfrath there are among other types six Seegar kilns, and five additional Seegar kilns are under construction. These kilns are of standard design and the daily output of each is about 90 tons with a fuel consumption of 18 per cent.

A Seegar kiln was erected in 1943 at Limberg; it works with forced draught and has an output of 90 tons per day of 16 hours with a coke consumption of 20 per cent.

Conclusions.

The works described in the report account for about one-third of the potential output of the German lime industry, that is about two million tons of the total annual capacity of 5½ million tons of lime. The relative proportions capable of being produced in kilns of various types are: In Hoffmann kilns, 32 per cent.; gas-fired kilns, 10 per cent.; Seegar kilns, 22 per cent.; in kilns of other types 36 per cent. In the works investigated there were 42 Hoffmann kilns, 18 Seegar kilns, 8 gas-fired kilns, and 59 other types of kilns.

Efficiency of Crushing and Grinding.

EVIDENCE is given by Mr. T. K. Prentice (quoted in "Building Science Abstracts," April, 1946) in the Journal of the Chemical, Metallurgical and Mining Society of South Africa, to support the conclusion that the energy absorbed in crushing and grinding is directly proportional to the new surface area produced in the crushed material. The efficiency of crushing and grinding machines varies from 20 per cent. to 40 per cent. As little as 55 per cent. of the total power used in operating the machine may be available for crushing or grinding, the remainder being absorbed by the prime mover or by mechanical losses. Over 80 per cent. of the energy available for crushing or grinding appears as heat and is thus dissipated.

The Use of Low-grade Coal in the Manufacture of Cement.

BECAUSE the war deprived the Spanish cement industy of high-grade imported coal, inferior fuel had to be used, and an account of the methods adopted is given in a recent number of "Rock Products."

Most of the kilns in Spain are of the ordinary type with the clinker discharging from the hood into an independently-operated cooler below. There are some Lepol kilns and other modern types with multiple coolers or with Allis-Chalmers coolers.

Most of the coal used during the war was flotation fines, anthracite fines, and low-quality lignites high in ash. The Asturias fines have the following characteristics: Volatile carbon, 12 to 18 per cent.; fixed carbon, 30 to 50 per cent.; ash, 35 to 45 per cent.; heat value, 5,000 calories. Trouble was encountered in drying this coal due to its fineness and high water content which made it stick to the dryers. If mills employing hot air for drying during grinding are used, the only trouble is that the draught aggravated by the small volume of material to be ground causes premature wear. It was found advisable to dry the material until it contained not over 1·5 per cent. of water when it leaves the mill.

Due to its low heat value a larger volume of the fuel is required, and a greater amount of primary air has to be used, but at a temperature not quite as high as with better quality fuel because the high ash content of low-grade fuel makes it more dense. The greater degree of diffusion prevents the air from conveying the volume of coal to be injected and the coal is partly deposited in the pipes. Therefore comparatively cold air is used; this cools the kiln, and makes the production of good quality clinker difficult. The clinkerization zone is moved towards the interior of the kiln, resulting in a low output.

Another factor is the high ash content of this fuel. Due to decreased draught the fuel remains longer in the kiln, and the ash is absorbed in the clinker increasing the percentage of acid elements. It is therefore necessary to increase the carbonates by introducing a hard-burning material into the kiln; this requires more fuel, which in turn results in more ash and a low-quality clinker.

The first step to increase the temperature of the kiln and obtain maximum use of the heat of low-grade fuel is to reduce to a minimum the amount of primary air. To this end another method of injecting the coal is employed. If an emulsion of hot air and coal is injected into the combustion zone, perfect combustion of the coal could be obtained even though the coal would not have good burning properties. However, such an emulsion would not remain in this state due to the different densities of its components, the coal rapidly separating from the suspension medium. To make this emulsion, very dense air must be used, that is cold air. An amount just sufficient to make a good emulsion with the fuel and ensure its complete conveyance into the combustion chamber should be used. To do this the fans blowing in the primary air should be replaced with others of

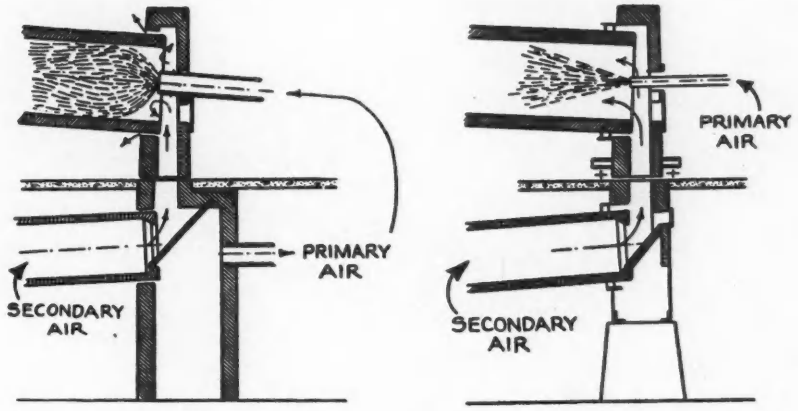
smaller capacity. To obtain a good mixture and ensure its dispersion with a small amount of air, the larger injection pipes conveying air at about 200 deg. C. cannot be used if the formation of sediments is to be prevented. The pulverized coal also could not be dropped in the path of the air blast. It would be necessary to use air under a predetermined pressure and a mixing device would have to be employed to obtain a homogeneous mixture with the least amount of air required to convey it a sufficient distance within the kiln.

Under normal conditions the coal-air mixture encounters a temperature of about 800 deg. C. within the kiln from the secondary air coming from the cooler. The coal emulsified in a small amount of cool air burns readily despite its low content of volatile matter and its high percentage of ash. Therefore high pressure and a small capacity must be used, varying according to the kiln dimensions. The best pressures are from 30 to 80 cm. of water and a capacity of from 15 to 50 metres per minute. The mixer may consist of a metal casing enclosing a detachable nozzle through which the pulverized coal is injected. A turbulent mixture is created in its passage through the injection pipe into the kiln burner. The dimensions of the nozzle and the required pressure should be determined in each case in relation to the volatile matter, ash and water content, and fineness of the ground coal. *Fig.* 1 (*a*) illustrates the difficulties encountered in burning low-grade fuel in a kiln designed to burn high-grade pulverized fuel. The primary air at low temperature occupies almost the entire combustion zone, obstructing the passage of the secondary hot air from the cooler. *Fig.* 1 (*b*) shows a kiln designed to burn low-grade fuel with a reduced volume of primary cool air, permitting utilization of a larger volume of secondary hot air from the cooler. It will be noted that the difficulties experienced with the normal process of combustion in absorbing the hot air from the cooler are not present in *Fig.* 1 (*b*) as the interference between the two air blasts at different temperatures has been eliminated. A blast of a mixture of cold air and coal of low volume is introduced into a large volume of hot air that envelops the cold mixture of air and coal.

Generally, the primary air can be reduced to 90 per cent. of that normally employed, provided the nozzle and the pressure are selected to obtain a good mixture. To avoid admission of cold air into the kiln and cooler when forced draught is not available or when the coolers are small, it is advisable to blow air into the cooler. This will activate the kiln draught and provide an ample volume of hot secondary air. With this arrangement combustion of the coal takes place as close to the lower end of the kiln as desired, the calcination zone being restricted. The preparation zone is therefore longer and the output is increased. There is no danger of the coal being blown over unburned as combustion starts the instant the coal enters the kiln. Consequently, greater draught may be supplied by opening the stack damper. The greater the volume of air drawn in the larger the combustion capacity. More fuel will be burned and this will result in increased output. This arrangement also permits the ash to be blown out of the kiln by the additional draught so that it is not absorbed by the raw materials and clinker, and the quality of the product is improved. This arrangement also makes it

possible to use a smaller amount of carbonates, thereby increasing the output.

Based on experience in burning low-grade fuels with various kilns, the following conclusions can be drawn: (1) The coal must be injected into the kiln with the least amount of primary air that permits a perfect mixture. To this end, high-pressure, small capacity fans and proper mixtures must be used; (2) The primary air must be cold so as to have the greatest mass in the least volume; (3) If the cooler is deficient in size, air must be blown through the end to avoid air leakage; in this way the amount of secondary hot air is increased; and (4) The stack damper should be opened as much as possible to blow ash out to prevent its absorption by raw material and clinker. These conclusions apply also to the



(a) (b)

Fig. 1.

so-called "adequate" fuels. Ease of combustion of these fuels implies a greater kiln combustion capacity, larger output and less fuel consumption. Perfect combustion of coal under these conditions makes it possible to burn fuel low in volatile matter or mixed with up to 20 per cent. of anthracite fines with a considerable increase in heat value. When lignite is used the percentage of anthracite can be increased provided the lignite is finely pulverized.

Labour Requirements in the Cement Industry in the United States.

AMONG the statistics of the labour requirements of certain industries in the United States given in the "Monthly Labor Review" for November, 1946, issued by the United States Department of Labor, it is stated that the production and transport of 100 barrels of cement require 100·49 man-hours. This is equivalent to about six man-hours per ton.

A Rotary Cement Kiln 475-ft. Long.

SOME results are now available of the operation of a rotary cement kiln 475 ft. long after the production of 650,000 tons of cement clinker over a period of five years. The kiln is at one of the works of the Marquette Cement Manufacturing Co. at Des Moines, Iowa, U.S.A., and its performance is described by Mr. Bror Nordberg in *Rock Products* for August, 1946. Generally it has been found that the kiln, which was designed to produce 165,000 tons of clinker a year by the wet process, produces a more uniform product than the shorter kilns it replaced and that its fuel efficiency when burning low-grade coal is excellent.

The length of the kiln and its diameter were based upon the time required for the conversion reactions, of evaporation and drying, calcination of $MgCO_3$ and $CaCO_3$, and the reaction between solid oxides and clinker formation, to give the expected capacity with a maximum utilization of heat from coal that is far inferior to grades burned throughout the industry. Iowa coal, as available for cement manufacture, has 17 to 18 per cent. of ash on a dry basis and over 5 per cent. of sulphur. Its heat value is only 9,300 to 9,500 B.T.U. per lb. A coal of high volatile matter, it gasifies at low temperature and more than average time is required for maximum heat transfer to the cement raw materials ; hence a long kiln is desirable, fired with a flame up to 90 or 100 ft. in length. The coal is pulverized to a fineness of 65 to 67 per cent. passing a 200-mesh sieve when the kiln is in normal production, assuming 15 per cent. or less contained moisture, in order to project a long flame extending maximum heat to the back end of the kiln.

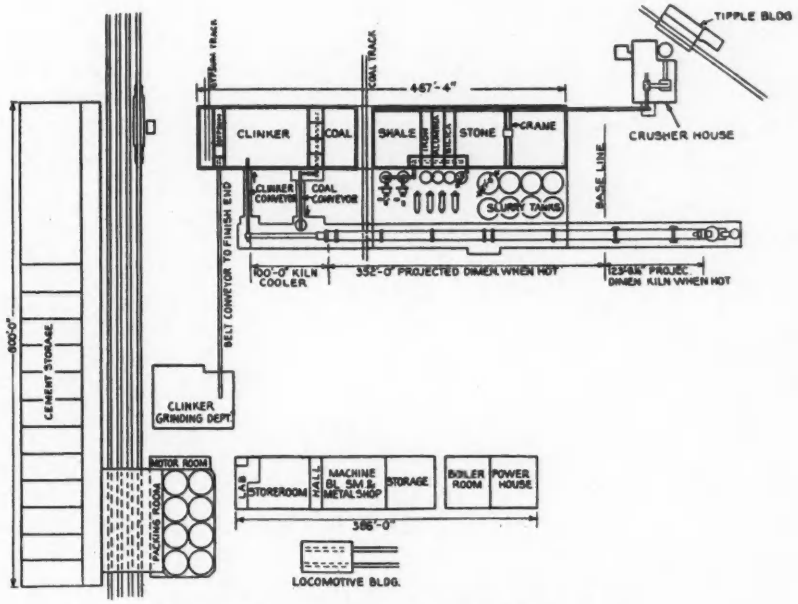
The kiln is of all-welded construction, of Allis-Chalmers manufacture, and is lined with insulating bricks except for the back 40 ft. of its length. It rotates on seven sets of 48-in. by 24-in. forged steel rollers. Fabricated from $\frac{3}{4}$-in. steel plate, with 2-in. plate under the tyres, the kiln weighs 1,600 tons including the heat transfer chains in the back of the kiln and the brick lining. The kiln is direct-fired by a unit coal mill, with preheated primary air taken from the kiln hood and secondary air from an air-quenching clinker cooler. The rate of slurry feed is synchronised with the kiln speed, which is variable. There are sufficient heat-exchange chains to give the advantage of a probable additional 100 ft. of kiln length. The control instrument panel has instruments for practically every measurable factor in kiln operation. Firing is under induced draught and there is a positive seal, by air under pressure, at the kiln hood, which is an important factor in maintaining constant draught conditions throughout the kiln.

The performance of the kiln must be considered with reference to the arrangement of the plant, since other departments, particularly the raw grinding mill, are closely related to it. For example, extremely uniform slurry is obtainable through careful blending of the slurry in the raw mill which is reflected, in part, in clinker that is exceptionally uniform in composition. An extremely long kiln

is, of course, a good blending machine in itself. The kiln requires close supervision by skilled burners with many indicating and recording instruments and automatic controls. Adjustments necessary due to variations in coal, for example, are made by the burner. The kiln has been the object of continuous experiment from the time it started operating with a view to improving heat exchange and quality of clinker.

At present the kiln is producing 510 to 530 tons of standard clinker per day, which, with changes in the kiln drive, will be increased to 570 tons. Fuel consumption is at the rate of 2,875 B.T.U. per lb. on an average, and the exit gas temperature is about 420 deg. F.

The slurry is fed into the kiln by a motor-driven Allis-Chalmers ferris-wheel feeder, synchronised with the kiln drive motor so that the rate of feed is automatically adjusted according to the kiln speed. The kiln has a variable speed



Plan of Cement Works with Kiln 475 ft. Long.

within the limits of 20 to 80 revolutions per hour. It is driven by a 125 to 150 h.p. direct current motor through a V-belt and a gear reducer. A small generator driven from the kiln motor operates a 5-h.p. motor that drives the ferris-wheel feeder. Adjustments in the speed of the feeder are effected by a variable-pitch speed changer. At the present production rate, the kiln speed averages 67 revolutions per hour. Higher production up to 570 tons per day has already been

reached and probably will be the standard, with the installation of an identical kiln drive, linked electrically with the existing one into a dual drive. Higher kiln speeds will be adopted, probably in the neighbourhood of 80 revolutions per hour.

The kiln has a pitch of $\frac{7}{16}$ in. to the lineal foot. At the average speed of 67 revolutions per hour, the travel of the materials through the kiln is approximately 2 ft. per revolution of the kiln. The clinker is burned at approximately 2,600 deg. F. and at a slightly higher temperature for high-early-strength cement. It discharges over a 4½ ft. by 100 ft. grate-type air-quenching clinker cooler.

The cooler is divided by a curtain into primary and secondary cooling sections, quick quenching to about 1,000 deg. F. taking place over the first 15 to 18 ft. of cooler, followed by gradual cooling over its length to the point of discharge. Separate fans, rated at 29,900 and 58,000 cu. ft. per minute, force cooling air through the primary and secondary clinker bed sections respectively, the pre-heated air through the fore section being the secondary air for combustion in the kiln and comprising 65 to 72 per cent. of the total combustion air. Air forced through the low-heat section of the cooler exhausts through a cyclone dust collector to a stack; this fraction of the heat is wasted. Clinker dust is returned to a channel alongside the clinker grate, so located that the dust is not recirculated to the collector.

The fans are driven by 30-h.p. squirrel-cage motors through V-belts, and the grate drive is an automatically-controlled 15-h.p. motor. An automatic rheostat control in the drive-motor circuit regulates the speed of the cooler grate, with rises or falls respectively in the pressure through the clinker bed. Clinker is cooled to the point where ½-in. size or smaller is actually cool at the point of discharge over a bar grizzly to a belt conveyor; pieces as large as a walnut may be held in the hand. The purpose of the bar grizzly is to reject any pieces of slag ring as they are discharged. No difficulty is experienced through slag ring formation, probably because of the large kiln diameter and a high silica content in the raw mix. The clinker is conveyed into covered storage over a 24 in. by 212 ft. heat-resisting conveyor belt.

Firing is by a Babcock and Wilcox direct-firing unit mill which is set to pulverize to a fineness somewhat coarser than usual when coals of higher heat value and containing less ash are burned. Primary air (28 to 35 per cent. of the total for combustion) is drawn from above the kiln hood and tempered to 400 deg. F. on entering the mill. The coal-air mix has a temperature of about 120 deg. F. on entering the kiln through an air-cooled burner pipe. The temperature is increased to 140 or 145 deg. F. in wet weather.

An 11 ft. 6 in. double air-seal nose ring seals and cools the firing end of the kiln. An independent blower forces air under slight pressure at 300 cu. ft. per minute around the castings and nose block, entering the kiln as a small part of the secondary air to support combustion. The drive on the fan is interlocked with the fan on the coal mill so that the coal mill fan cannot be started until the air seal is operating. In effect, the kiln is a closed furnace.

Kiln Lining.

The kiln is lined with refractory blocks except for the back 40 ft. of length, 35 ft. of which is in the chain section. Lining from that point forward, into the zones of increasing temperatures, consists of 72 ft. 8 in. of 4½-in. 40 per cent. alumina wear-resisting blocks (chain section); 69 ft. 5¾ in. of 6-in. 40 per cent. alumina bricks; 196 ft. of 6-in. 40 per cent. alumina bricks with 2½ in. thickness of 6 in. by 30 in. insulating blocks set in semi-refractory cement; 38 ft. 9 in. of 9-in. 70 per cent. alumina bricks; 41 ft. 2 in. of 6-in. magnesite bricks; 13 ft. 9 in. of 9-in. 70 per cent. alumina bricks with 70 per cent. alumina kiln nose blocks. The life of magnesite basic bricks in the hottest zone has been satisfactory. By increasing the coal or reducing the primary air input to the kiln, and thereby increasing the CO in the gases, an 8-in. protective coating is built up on these bricks in a few hours.

Originally the kiln was equipped with 19,600 linear feet of ⅝-in. heat-exchange chains extending through 105 linear feet of the kiln length in the drying section. There will be a reduction to 90 ft. of ¾-in. chain, some 12,000 linear feet, when the kiln is shut down for major maintenance. The life of the chains is nearly four years.

The formation of mud rings has been completely eliminated by regulating the slurry viscosity through the chain section. Some difficulty experienced earlier with the formation of mud rings in the chain section has been eliminated by causing the viscosity that inhibits ring formation to occur at a definite point in the kiln, within a few feet of the end of the chains where the whipping action of the links will dislodge the nodulized material as fast as it is deposited. The tendency had been for rings to start building behind the fittings from which the chains are hung inside the kiln. This critical point in viscosity, when the slurry is sticky and will form rings in the presence of great quantities of dust, is at 17 to 19 per cent. moisture.

The feed into the kiln is a slurry containing 37½ to 38½ per cent. moisture, which is the ideal based upon best periods of running but has variations according to the requirements of the slurry pumps in the raw mill. The amount of contained water in the slurry, as handled by pumps in the raw mill, is not important, the objective being the best consistency for efficient handling. Variations in consistency may be due to water leaking through the seals of the slurry pumps, or may become necessary with variations in the raw materials or in the fineness of the grind, which normally is kept at 91 per cent. passing a 200-mesh sieve. Chemically, there is almost no variation in the kiln feed material.

The control of mud rings is a matter of controlling viscosity with a minimum sacrifice of heat. Too dry a material coming from the chain section would indicate waste of heat through the hotter section of the kiln and result in excessive dusting. The best viscosity is 12 to 17 per cent. of moisture as the material comes from the end of the chain section.

Eight 2⅞-in. holes through the kiln shell, starting at about 5 ft. from the unlined section into the bricked section and spaced at 9-ft. to 10-ft. intervals longitudinally,

are provided for guarding against flooding and mud ring formation. A check of viscosity reduction through the entire chain section is made after a kiln change. No dust collector is provided.

Instruments.

The kiln is fired under induced draught by a fan rated at 150,000 cu. ft. per minute at 4-in. static pressure, driven by a 200-h.p. slip-ring induction motor with a speed of 200 to 900 revolutions per minute. There are automatically-controlled louvre dampers on the fan inlet connections. The draught in the kiln controls the volume of secondary air for combustion, the draught being maintained at 0.2 in. at the hood and minus 2 in. at the stack outlet. Hood-draught control is considered the most important single regulating device in firing the kiln. Firing is done with a slight excess of air to prevent too rapid coating in the kiln, a typical analysis of the exit gases (420 to 440 deg. F.) being 0 CO, 0.7 to 1 per cent. O_2, 26 to 28 per cent. CO_2, and less than 0.5 per cent. free CaO. Stack temperatures could be reduced further so far as the kiln is concerned, but a safe margin against condensation is desired.

The theory of operation is to develop as nearly ideal firing conditions as practicable and to have sensitive control, through a rheostat, of kiln speed. Otherwise, with constant kiln speed, adjustments in other factors, for example, hood or back end draught, primary or secondary air, coal variables, etc., would prevent the accurate balance desired. In starting the kiln, the speed is set at approximately the correct figure, bringing the other variables as close to the ideal balance as practicable to stabilize the burning and then make the necessary minor kiln speed changes. The kiln speed may be changed between 20 and 80 revolutions per hour in increments of 1 revolution per hour or less from the master control panel at the kiln hood, the compensating change in speed of the ferris-wheel feeder being very slight for kiln speed changes of less than 10 revolutions per hour. It is said that approximately three days are required to bring the kiln up to normal production, in stabilizing the firing variables while permitting gradual expansion of the lining to fill the space between the lining and the shell which occurs in cooling.

Exit-gas temperatures are kept uniform and the coal-air temperature and the clinker temperatures are controlled through litre weight tests (for hardness of burn) made at intervals. As an indicator of kiln temperatures, a Leeds-Northrup Ray-o-tube pyrometer sighted on the clinker at the far end of the flame records temperatures at that point, dusting preventing sighting of temperatures within the hottest zone.

Instrument Controls.

The master control electrical panel for kiln operation is claimed to be one of the most complete in the industry, and includes :

(1) Micromax burning zone temperature (indicating and recording) ; (2) automatic draught control ; (3) clinker production (recording-weightometer) ; (4) three-pen draught recorder (unit coal mill) ; (5) kiln revolutions counter ; (6) slurry wheel

counter ; (7) d.c. amps. to generator on kiln motor (indicating) ; (8) a.c. amps. from generator (synchronous tie) ; (9) a.c. volts from generator (synchronous tie) ; (10) kiln speed, r.p.h. (indicating and recording) ; (11) feed and temperature recorder (stack-recording) ; (12) two-pen draught recorder (firing and feed end) ; (13) cooler pressure manometer (indicating) ; (14) manual-automatic cooler control ; (15) temperature recorder (air to coal mill, coal-air mix) ; (16) air weight control to cooler (automatic damper regulation) ; (17) air temperature control to coal mill (automatic) ; (18) mill level control (coal-automatic) ; (19) damper position indicator ; (20) red damper position—full open (lights) ; (21) red damper position—full closed (lights) ; (22) overflow flasher (ferris wheel) ; (23) No. 1 cooler fan (light) ; (24) No. 2 cooler fan (light) ; (25) rheostat for coal mill fan (control—manual) ; (26) rheostat for kiln drive motor (control—manual) ; (27) switch for induced draught fan ; (28) switch for multicyclone fan ; (29) switch for cooler-drive motor ; (30) switch for coal-mill air-seal fan ; (31) switch for coal-mill fan ; (32) switch for coal-mill ; (33) switch for coal-mill feeder ; (34) kiln amps. (indicating) ; (35) coal-mill amps. (indicating) ; (36) push-button for kiln motor ; (37) slow-speed rheostat for coal feeder ; (38) high-speed rheostat for coal feeder ; (39) switch for forced cooling air to kiln firing end ; (40) switch for cooler secondary air fan ; (41) switch for sealing air fan (coal mill) ; (42) clinker belt switch ; (43) red signal light for kiln and cooling fan ; (44) amber clinker belt flasher ; (45) green light for plus pressure on air seal.

Freezing and Thawing Tests.

A NEW METHOD OF OBSERVATION.

IN order to determine the effects of the rates of freezing and thawing upon the volume changes (transient and permanent) of concrete, a method has been devised by Mr. Rudolph C. Valore, Jr., of the Concrete Materials Section of the United States National Bureau of Standards, for making continuous observations of the volume changes. In this method, volume changes are indicated by the displacement of mercury from a steel dilatometer into a burette graduated in hundredths of a millilitre. The cylindrical test specimen (2 in. by 7·25 in.), with a thermo-element at its centre, is sealed into the dilatometer, and the entire assembly is placed in a liquid bath in which the temperature cycle of + 40 deg. to — 20 deg. to + 40 deg. F. is traversed at various rates.

For air-dried concrete specimens the volume changes were found to be uniformly linear and independent of the rate of temperature change. Coefficients of linear thermal expansion of 6×10^{-6} per deg. F. were indicated for a concrete containing siliceous sand and $\frac{3}{8}$-in. gravel and 564 lb. of Portland cement per cubic yard of concrete. In moist specimens of the same composition, departures from the linear volume-temperature relationship were ascribed to freezing or thawing of water within the capillary structure of the concrete. The contraction

of a specimen during cooling was interrupted as the water froze, and expansion during heating was retarded as ice melted.

When cooled slowly (10 deg. F. or less per hour), moist specimens showed uniform contraction to temperatures as low as 21·5 deg. F., or 10 deg. F. below the normal freezing point of the water in the concrete. Following this apparent supercooling effect there was an abrupt increase in volume and temperature as water within the specimen began to freeze. When the temperature was gradually lowered after freezing had begun the specimen again contracted uniformly, but at a greater rate than before freezing. In most cases the total contraction during the slow cooling from + 40 deg. to — 20 deg. F. was greater for the moist than for the air-dried specimens, despite the abrupt increase in volume of the moist specimens as freezing began.

The magnitude of this increase depended mainly upon the degree of moisture saturation of the concrete, the extent to which the specimen had been weakened by previous freezings, and the temperature to which the water in the specimen could be supercooled before freezing. It was found that the degree of supercooling could be controlled by varying the period of time between freezing and thawing cycles during which the specimen remained unfrozen. Supercooling was virtually eliminated when this "recovery" time before a cycle was reduced to a minimum, but it was at a maximum when this time exceeded 100 hours.

During the fastest cooling (+ 40 deg. to — 20 deg. F. in 30 minutes) moist specimens showed smaller amounts of contraction than during the slow cooling. These contractions became smaller as the specimen was weakened with each succeeding fast cycle. In addition, a rapidly-cooled specimen maintained at — 20 deg. F. showed shrinkage lasting for several days before reaching constant volume, whereas, when cooled sufficiently slowly, the volume at any temperature during a given cycle was an irreducible minimum.

The volume of a moist specimen was usually greater at the end of a cycle of freezing and thawing than at the start. The amount of this residual expansion for each cycle varied directly with the rate of cooling, the degree of supercooling, the number of cycles previously undergone by the specimen, and the degree of saturation of the concrete. The residual expansion varied inversely with the rate of thawing.

On the basis of residual expansions, the combination of the fastest freezing and the slowest thawing appeared to be most destructive; and the slowest freezing (with a minimum of supercooling) combined with fastest thawing was the least destructive of the treatments to which these specimens were subjected. No attempt was made to analyze stresses on the basis of transient volume changes and elastic properties for moist specimens, as stresses so computed would be, in some cases, several times greater than the nominal tensile strength of the concrete.

French Standard Specifications for Cements.

THE French standard specifications for cements of various kinds were re-issued in 1946 with a new series of reference numbers, namely NF.P15-301 to 310, and in a new form, that is as a single sheet for each type of cement. These standards supersede and replace the specifications comprised in B1-1 (1935), but do not necessarily differ therefrom in basic requirements, although there are variations in some particulars. In the following, the complete requirements are given for seven types of cement.

The standard procedures for testing cement are given in NF.P15-301 and are not repeated in each separate standard. An appendix common to all cements gives the commercial clauses. There are no clauses relating to fineness, and an initial setting time of not less than 30 minutes is applicable to all the cements. No final setting time is specified. The cements are defined by the specified minimum compression strengths at 7 days and 28 days; thus ordinary artificial Portland cement is designated "CPA160-250," the two values being the minimum strengths in kilogrammes per square centimetre at 7 days and 28 days respectively.

Types of Cement.

The types of cement included are: Ordinary artificial Portland cement (P15-302: CPA160-250); Rapid-hardening Portland cement (P15-302: HRI315-400); Iron-Portland-cement (P15-303: CF160-250); Blastfurnace-slag cement (P15-304: CHF100-160); Clinker-slag cement (P15-305: CLK100-160); Lime-slag cement (P15-306: CLX50-100); Masonry cement (P15-307: CM100-160); and Natural cement (P15-308: CN100-160).

Iron-Portland-cement (ciment de fer) is described as the product resulting from a finely ground mixture containing 70 to 80 parts of Portland cement clinker and 20 to 30 parts of granulated blastfurnace slag with the addition of a small quantity of calcium sulphate.

In blastfurnace-slag cement (ciment de haut-fourneau) the proportions are approximately reversed, there being 30 parts (± 5 per cent.) of cement clinker, 70 parts (± 5 per cent.) of granulated blastfurnace slag, and a small amount of calcium sulphate.

Clinker-slag cement (ciment de laitier au clinker) is defined as the product resulting from a homogeneous and finely ground mixture of blastfurnace slag and cement clinker, the maximum amount of the latter being 20 per cent. of the total weight. Calcium sulphate may be added.

Lime-slag cement (ciment de laitier à la chaux) is a mixture of common or hydraulic lime and granulated blastfurnace slag, there being 70 per cent. of the slag. Various reagents such as sodium sulphate or sodium carbonate, acting as accelerators, are permitted, but the addition of inert material is prohibited.

Masonry cement (ciment à maçonner) is a cement in which the essential active elements are identical with those in Portland cement but of which the method of manufacture produces a cement less uniform than, and inferior to, Portland

cement. This type of cement may be obtained by mixing artificial cement or natural cement with other hydraulic or inert materials as the manufacturer wishes, as long as the requirements of the specification are met. Inert materials must not exceed 35 per cent. of the total. The addition of calcium sulphate is permitted so long as the content of SO_3 does not exceed the specified maximum proportion after the deduction of the amount of inert material. The addition of blastfurnace slag is permitted up to 50 per cent. of the weight of the active constituents after deduction of the weight of the inert material. These cements cannot be termed Portland cements unless they satisfy the requirements of resistance and chemical composition of P15-302.

Natural cement (ciment naturel) is the product resulting from grinding clinkerised stones obtained by burning, at a suitable temperature, marly limestones of which the composition is very uniform and is approximately that of the mixtures of clay and calcareous material used in the manufacture of artificial Portland cement. The addition of calcium sulphate is permitted. The product obtained from the grinding, without the addition of other materials, of selected natural products arising from the burning of hydraulic lime are also considered as natural cements.

The addition of a controlled amount of calcium sulphate is also permitted in the manufacture of ordinary Portland cement (ciment Portland artificiel) and rapid-hardening Portland cement (ciment Portland à haute résistance initiale). The addition, after burning, of foreign materials other than water and calcium sulphate must not exceed 3 per cent. in these cements as well as in iron-cement, blastfurnace-slag cement, and clinker-slag cement. The addition, after burning and as reagents, of soluble salts (chlorides in particular) is prohibited in the case of ordinary Portland cement and natural cements, but such additions are allowed in the manufacture of rapid-hardening Portland cement, iron-cement, and blastfurnace-slag cement so long as the amount of anhydrous salt does not exceed 1 per cent.; if advantage is taken of this provision the nature of the reagent used must be stated on the bag containing the cement.

Chemical Requirements.

The proportion of sulphuric anhydride (SO_3), after taking into account the effect of any calcium sulphate added to the basic materials, must not exceed 3 per cent. for any of the cements mentioned, except in the cases of natural cement, clinker-slag cement, and lime-slag cement for which the limit is 5 per cent.

The proportion of insolubles, as determined by the hydrochloric acid test with the renewal of the sodium carbonate, must not exceed 3 per cent. for any cement except natural cements, for which 4 per cent. is permitted.

The loss on ignition at 1,000 deg. C. must not exceed 4 per cent. for ordinary and rapid-hardening Portland cement, 5 per cent. (after correction for sulphates) for iron-cement, blastfurnace-slag, cement and clinker-slag cement, and 6 per cent. for natural cement. The test is to be made on the fresh product and not after aeration. No limiting loss on ignition is specified for lime-slag cement.

The proportion of magnesia in ordinary or rapid-hardening Portland cements must be less than 5 per cent.

The proportion of calcium oxide CaO is limited to 50 per cent. in clinker-slag cement and 55 per cent. in blastfurnace-slag cement.

For the purpose of the chemical analysis of masonry cement, materials considered chemically inert are those insoluble in hydrochloric acid and the sodium carbonate, and calcium and magnesium carbonate. In the application of this clause it is permitted to assume that double the weight of the CO_2 liberated by the HCl represents approximately the weight of the carbonates.

Expansion.

The standard test for expansion must show, for all cements, an expansion not exceeding 10 mm. after boiling for three hours. If the proportion of magnesia in ordinary and rapid-hardening Portland cements, masonry cement, and natural cement exceeds 3 per cent., the duration of the test must be prolonged until for a period of two hours there is no increase in the expansion, and at the end of the test the expansion must not exceed 10 mm.

Strength.

The criterion of strength is the compressive strengths at specified ages of standard mortar test pieces. These strengths are 2,276 lb. per square inch at 7 days and 3,556 lb. per square inch at 28 days for ordinary Portland cement and iron-cement. The optional minimum tensile strengths for these cements are 284 lb. per square inch at 7 days and 356 lb. per square inch at 28 days. For rapid-hardening Portland cement the compressive strengths required are : 2 days, 2,276 lb. per square inch ; 7 days, 4,480 lb. per square inch ; 28 days, 5,689 lb. per square inch. The corresponding tensile strengths in lb. per square inch are 256, 356, and 427 respectively. The compressive strengths for blastfurnace-slag cement, clinker-slag cement, masonry cement, and natural cement at 7 and 28 days respectively are 1,442 lb. per square inch and 2,276 lb. per square inch. For lime-slag cement the corresponding strengths are 711 and 1,422 lb. per square inch.

Durability of Concrete and Fineness of Cement.

IN 1944 a survey of a number of reinforced concrete bridges in the western part of the United States was made in the course of an investigation undertaken by the Public Roads Administration to determine the causes of the rapid deterioration of such structures experienced in the Western States.

It was found that bridges built before 1930 showed less disintegration than those erected subsequently. In a review of the investigation, Mr. F. H. Jackson, Principal Engineer of Tests of the Public Roads Administration, states that since in the past twenty years there have been improvements in construction methods, supervision, and methods of preparing and grading aggregates, and since the character of aggregates has not changed, modern cement was suspected of being responsible. Comparing present-day cements with the older types, in

searching for some characteristic that tended to lower resistance to weathering, the one outstanding difference was the fineness. Recently there had been advanced a theory that might account for the supposition that modern cements did not make as durable concrete as the more coarsely-ground cements used 25 years ago. According to this theory, the maximum limit of 2 per cent. of sulphur trioxide given in the A.S.T.M. specifications, while satisfactory for the coarser-ground product, was not high enough for the more active, finer ground cement. This applied particularly to cement with a high tricalcium aluminate content, since it was largely for the purpose of regulating the hydration of this compound that gypsum was employed. Recent investigations by the Portland Cement Association of the United States indicated that, from the standpoints of both strain and drying shrinkage, cements with high and moderately high tricalcium aluminate content were improved by adding higher percentages of gypsum than were allowed by the present American specifications. Furthermore, even cements of low tricalcium aluminate content appeared to be similarly improved when the alkali content was high. There were also some indications that drying shrinkage might be influenced by the alkali content of the cement independently of the calcium aluminate content. The Portland Cement Association was now engaged in a study of this problem to determine by laboratory freezing and thawing tests whether the use of larger quantities of gypsum would improve durability. The foregoing report is abstracted from a recent number of "Engineering News-Record."

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